Like Father, like Son: Young Children's Understanding of How and Why Offspring Resemble Their Parents

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Source: *Child Development*, Vol. 67, No. 1 (Feb., 1996), pp. 151-171
Published by: Wiley on behalf of the Society for Research in Child Development
Stable URL: http://www.jstor.org/stable/1131693
Accessed: 28-08-2017 18:46 UTC

Like Father, Like Son: Young Children's Understanding of How and Why Offspring Resemble Their Parents

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SOLOMON, GREGG E. A.; JOHNSON, SUSAN C.; ZAITCHIK, DEBORAH; and CAREY, SUSAN. *Like Father, Like Son: Young Children's Understanding of How and Why Offspring Resemble Their Parents.* CHILD DEVELOPMENT, 1996, **67**, 151–171. 4 studies investigated the broad claim that preschoolers understand biological inheritance. In Study 1, 4–7-year-old children were told a story in which a boy was born to one man and adopted by another. The biological father was described as having one set of features (e.g., green eyes) and the adoptive father as having another (e.g., brown eyes). Subjects were asked which man the boy would resemble when he grew up. Preschoolers showed little understanding that selective chains of processes mediate resemblance to parents. It was not until age 7 that children substantially associated the boy with his biological father on physical features and his adoptive father on beliefs. That is, it was not until age 7 that children demonstrated that they understood birth as part of a process selectively mediating the acquisition of physical traits and learning or nurturance as mediating the acquisition of beliefs. In Study 2, subjects were asked whether, as a boy grew up, various of his features could change. Children generally shared our adult intuitions, indicating that their failure in Study 1 was not due to their having a different sense of what features can change. Studies 3 and 4 replicated Study 1, with stories involving mothers instead of fathers and with lessened task demands. Taken together, the results of the 4 studies refute the claim that preschoolers understand biological inheritance. The findings are discussed in terms of whether children understand biology as an autonomous cognitive domain.

Carey's (1985, 1988) claim that an autonomous domain of biology is not constructed until the end of the first decade of life has come under concerted criticism (e.g., Gelman & Wellman, 1991; Inagaki & Hatano, 1993; Keil, 1989, 1994). At issue here are the explicit, accessible, conceptual representations—the framework theories—that are fundamental to the organization of conceptual knowledge. We can credit children with an autonomous cognitive domain only if they can be shown to represent: (1) a set of *phenomena*, involving (2) a domain of *ontologically distinct* entities, and (3) unique *causal mechanisms*, which provide explanations for the phenomena in the domain and the properties of the entities in it (Carey, 1985). Wellman and Gelman (1992) further point out that in an autonomous domain, domain-specific causal mechanisms operate in a manner that respects ontological distinctions within a *coherent* causal explanatory framework. The notions of ontological distinctions and coherent causal explanatory frameworks are spelled out in related ways by Carey (1985, in press), Keil (1979, 1989),

We wish to thank Adebisi Lipede, Adee Matan, Veronica Mendoza, David Millstein, Kelly Olguin, Virginia Slaughter, Helen Tager-Flusberg, Linda Tickle Degnen, Mary Gale and the Cambridge Montessori School, Lynn Stuart and the Cambridge School District, Linda Rings and the Cambridge Compass Program, and the Solomon Schector Day School. This research was supported by grant 91-20 from the James S. McDonnell Foundation to the first author and grant 5-T32-MH18823 from NIMH to the second author. Please send correspondence concerning this article to the authors at the Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, 79 Amherst Street, Cambridge, MA 02139.

[*Child Development*, 1996, **67**, 151–171. 0009-3920/96/6701-0014$01.00]

Murphy and Medin (1985), and Wellman and Gelman (1992).

The above criteria for autonomous domains are not independent. For example, "ontological distinction" and "explanatory framework" are interdefined; not all conceptual distinctions are ontological distinctions (Carey, 1985; Keil, 1979). Cats are distinguished from dogs, but this is not an ontological distinction. Carey (1985, in press) argues that ontological distinctions are those between entities embedded in different causal/explanatory frameworks. Researchers who claim that children understand an autonomous domain of biology have established that preschool children realize that animals (and perhaps also plants) are distinguished from other entities, because they undergo processes such as growth that other kinds do not (e.g., Keil, 1994; Rosengren, Gelman, Kalish, & McCormick, 1991). But in order to claim that these are understood as ontological distinctions by *children*, one must demonstrate that children have an explanatory framework that includes knowledge of biological causal mechanisms pertinent to such animal-specific phenomena.

The question, then, is whether preschool children know *any* causal explanatory mechanisms that are uniquely biological. Studies from several laboratories have been taken as providing evidence that children know at least one such mechanism, one that explains why blond parents tend to have blond children. That is, it is claimed that preschool children have a biological understanding of the inheritance of properties (Gelman & Wellman, 1991; Springer, 1992; Springer & Keil, 1989). However, a close review of these studies reveals them to be inconclusive.

A biological understanding of the inheritance of properties includes, at a minimum, two essential components: *Resemblance to Parents* and *Mediation by Reproduction*. First, there must be some understanding that offspring will resemble their parents with respect to variation among species (e.g., dogs have baby dogs not baby cats) and with respect to variation among individuals of the same species (e.g., black parents tend to have black children). And, second, there must be some understanding of the ways by which children may come to resemble their parents that entails a uniquely biological (as opposed to a psychological or mechanical) chain of causation. To be credited with a biological concept of inheritance, children need not understand anything like a genetic mechanism, but they must have some sense that the processes resulting in Resemblance to Parents differ from learning or other environmental mechanisms. Curly-haired parents may have curly-haired children because they give them permanents; prejudiced parents may have prejudiced children because they teach them to be so. These are not examples of biological inheritance. Inheritance, the biological origin of an animal's biological features, must be causally linked to birth, the biological origin of the animal. And as the biological parent is causally associated with birth and birth is causally associated with the origin of the body, so is the biological parent causally associated with bodily properties. Thus, the second component: Children understand biological inheritance only to the extent that they understand that, for certain characteristics, the chain of processes underlying Resemblance to Parents crucially involves birth. These characteristics include those bodily traits, such as skin color, that do not change during a person's lifetime. Finally, children's understanding of inheritance is part of a larger framework of biological causal explanation only if birth is implicated in the origin of bodily features and not in the origin of beliefs and other properties that children know to be learned. Inheritance judgments must distinguish among properties in a manner that is consistent with the finding that preschool children know minds and bodies to be ontologically distinct (Inagaki & Hatano, 1993; Keil, 1989; Wellman & Gelman, 1992).

In this article we explore whether 4–7-year-olds understand biological inheritance. We grant that preschool children understand the general notion of Resemblance to Parents. For example, Springer (1992) found that 4–8-year-olds understand that offspring resemble their parents. He told children that a pictured animal has an unusual property (e.g., "this horse has hair inside its ears"). He probed for projection of this property to a physically similar animal, described as a friend unrelated by birth to the target, and to a physically dissimilar animal, described as the target's baby. At all ages, the property was projected more to the baby than to the friend. This important result confirms the mounting evidence that preschool children are not appearance bound (Flavell, Flavell, & Green, 1983; Wellman & Gelman, 1988) and establishes the Resemblance to Parents component of an understanding of biological inheritance. However, because the study does not probe the mechanisms responsible for resemblance, it cannot bear on the second component.[1] Springer (1992) successfully distinguished what he considers a biological relationship (parentage) from a social relationship (friendship), but, as Carey (1985, 1988) pointed out, parentage is also a social relationship. At the very least, one would like to see biological parentage distinguished from nonbiological parentage such as adoption.

The same issue arises with respect to the data of Springer and Keil (1989). Adults and 4–7-year-old children were told that both parents of an animal had a particular property atypical of the species (e.g., pink rather than the usual red hearts) and were asked whether that animal would be born with the property. Springer and Keil manipulated further information about the abnormal property such as how the parents got it (whether they were born with it or acquired it in an accident), whether the property was internal or external, and whether it was described as having "biological" functional consequences. Two important results emerged: First, only adults based their judgments solely on whether the parents were born with the property. That is, only adults related birth to inheritance. The children did not appreciate that birth plays a mediating role in the process by which offspring come to resemble parents. Second, preschool children did make systematic judgments; they were influenced by whether the property was described as having "biological functional consequences" or not. From this result, Springer and Keil concluded that preschoolers have a biological concept of inheritance. This conclusion must be tempered due to the lack of analysis of what is to be considered a biological functional consequence. For example, Springer and Keil took "help them to see their enemies" as a biological functional consequence and "scared away all their friends" as a nonbiological functional consequence of "big, stretched-out eyes." But even if we grant these designations, the result merely establishes that preschool children expect Resemblance to Parents for such properties. Again, to probe further for an appreciation of birth as part of the causal process mediating the acquisition of certain properties, it would be necessary to compare natural parentage and adoptive parentage.

Gelman and Wellman (1991) specifically contrasted nature and nurture. They asked, for example, whether a cow, Edith, who had been separated from other cows at birth and raised with pigs, would moo or oink and whether she would have a straight or a curly tail. Even 4-year-olds judged that Edith would moo and have a straight tail. But the result does not bear directly on inheritance (nor was it intended to do so): The story asserts that Edith is a cow, in spite of having been raised in the company of pigs, and so it prejudges the question of interest. There is a wealth of evidence, most of it from Gelman herself, that preschoolers take category membership as predictive of category-relevant properties in the face of conflicting information (Gelman, 1988; Gelman & Markman, 1987). Furthermore, Gelman and Wellman's stories did not stress that the baby cow was raised in a pig family, an offspring among other offspring who were pigs. Thus, it did not cleanly contrast adoptive and biological family relationships.[2]

To fill the gap in the literature, the studies presented here contrast adoptive and biological family relationships in determining Resemblance to Parents. Study 1 uses both direct and indirect methods of examining what mechanisms children believe mediate similarity between offspring and parents. It indirectly assesses children's understanding by examining whether their pattern of judgment depends upon what kind of property is at issue. A pattern of judgment that offspring will resemble their biological parent on physical properties and their adoptive parent on clearly nonphysical properties would provide indirect evidence for a differentiation of two classes of mediating processes by which offspring come to resemble parents. Study 1 also directly examines children's understanding of the mechanisms mediating resemblance between parents and offspring by asking them for explanations of their judgments.

[1] Springer and Keil (1991) did explore children's understanding of various mechanisms, but those data are inconclusive (see General Discussion).

[2] Gelman and Wellman did attempt to test whether category information was driving the inference. They posed stories about a seed described as coming from one plant (e.g., an apple) and grown in the environment of another (e.g., in a flower pot, in the company of flowers). By age 5, children judged it would come up an apple rather than a flower. But here they were contrasting *family* with *environment* (like Springer, 1992), not *adoptive* versus *biological* family. Thus, they again established that children know that offspring resemble parents.

Study 1: Similarity to Adoptive and Biological Parents

Method

Forty-eight children from Boston area schools and day-care centers participated in the study, 16 each in the 7-year-old group (M = 7-7, range = 7-0 to 7-11), the 6-year-old group (M = 6-5, range = 6-0 to 6-11), and the preschooler group (M = 5-1, range = 3-11 to 5-10). Sixteen adults also participated in the study. The subjects included black, white, and Asian males and females of different economic backgrounds. The adults ranged from high school graduates to those with advanced degrees. There was no effect of level of education on adult performance.

The subjects were interviewed individually. Each interview took approximately 10 to 15 min. The subjects were read a fairy tale in which a little boy is born to a king and adopted by a shepherd or one in which a little boy is born to a shepherd and adopted by a king (see Appendix A). The experimenters pointed to schematic line drawings of the king, the shepherd, the boy, the king's castle, and the shepherd's hut in order to maintain the children's interest and make the story clearer. None of the features subsequently probed in the task is represented in the pictures. Before proceeding with the testing, the experimenters questioned the subjects to make sure that they understood the story. They asked, "Where was the little boy born?" and "Where did he grow up?" Two children did not respond correctly and were dropped from the study. When the experimenters were confident that the subjects understood the story, they asked a series of 18 inheritance questions in a two-alternative, forced-choice paradigm. The biological parent was described as having one of a pair of features, the adoptive parent as having the other, and the subjects were asked what they thought the little boy would be like when he grew up. For example, "The king has green eyes and the shepherd has brown eyes. When the little boy is all grown up and is a young man, do you think that he will have green eyes like the king or brown eyes like the shepherd?" If subjects did not answer they were encouraged to do so, and if they chose something other than one of the two alternatives, that response was noted and the question was repeated. Children were encouraged to provide explanations of their judgments; the adults were not asked for explanations.

The 18 feature pairs were divided among five types of traits (see Table 1). The contrast of greatest theoretical interest is between the six physical traits (e.g., liver on the right/liver on the left) and the three beliefs (e.g., believes that skunks can see in the dark/believes that skunks cannot see in the dark), for a differentiation of these traits lies at the heart of the distinction between resemblance to family due to biological causes and that due to teaching and learning causes. The nine other traits were divided among three preferences (e.g., likes candy more than pickles/likes pickles more than candy), three skills (e.g., is better at football than baseball/is better at baseball than football), and three temperaments (e.g., laughs all the time/is angry all the time). These traits were included mainly for exploratory reasons. Experts who study heritability of such traits are divided as to the degree of biological determination of them, but it was our intuition that adults in our culture consider them to be mainly under environmental influence, their acquisition mediated by teaching and learning.

The experiment was balanced across subjects to control for the following possible

TABLE 1

List of Study 1 Feature Pairs, by Trait Type

Physical traits:
has green eyes/has brown eyes
has a high voice/has a low voice
has curly hair/has straight hair
is tall/is short
has liver on right/has liver on left
has pink heart/has red heart
Beliefs:
believes that skunks can see in the dark/believes that skunks cannot see in the dark
believes that tin cans rust/believes that tin cans do not rust
believes that oil floats in water/believes that oil sinks in water
Preferences:
likes candy more than pickles/likes pickles more than candy
likes cats more than dogs/likes dogs more than cats
likes parties more than movies/likes movies more than parties
Temperaments:
is shy/likes to meet new people
doesn't share things/shares things
laughs all the time/angry all the time
Skills:
is better at reading than at counting/is better at counting than at reading
is better at football than at baseball/is better at baseball than at football
is better at cooking than at sewing/is better at sewing than at cooking

confounds: whether the king or the shepherd was the biological father; whether the king or the shepherd was mentioned first during the forced-choice questioning (thereby avoiding the confound of having, for example, the king always described as being tall and the shepherd always short); and which combinations of features were true of the same father (two different shufflings of features were used so that, for example, having brown eyes sometimes went with being tall and sometimes with being short). The features were interspersed to control potential order effects. There were, all told, eight different experimental versions. A preliminary analysis revealed no significant effects related to the different versions.

Results

The goal of the present analysis was to identify individual subjects who showed evidence of having reasoned differentially about the origins of Physical traits and Beliefs. The Preferences, Temperaments, and Skills had been included in the study in order to explore whether children might consider them to be unique in some way. In fact, the subjects judged them quite similarly and much like the Beliefs (they had not been predicted to vary). The greatest difference shown among these four types of traits, in percent of features judged to resemble the biological father, at any age, was only 10 percentage points. Therefore, for the purpose of smoother exposition, the following analyses focus on the theoretically critical contrast of the Physical traits and Beliefs.

Pattern of responding over trait types.—The subjects were characterized according to their individual judgment patterns. The most important of these initial pattern groups was the *Differentiated* pattern group, defined to include those subjects who did distinguish between the physical traits and beliefs. Subjects were considered to have shown a Differentiated pattern if they judged the boy to resemble his biological father on at least five of the six Physical features and on none of the three Beliefs or on all six of the Physical features and on one of the Beliefs. The probability (binomial theorem) of an individual subject's showing such a pattern by chance is .0195. Of those subjects who did not meet these criteria for inclusion into the Differentiated pattern group, three further categories capture their response patterns. A number of children showed a bias to judge the boy to resemble one of the parents on virtually all features, regardless of trait type. Subjects were considered to have shown an *Adoptive Parent bias* pattern if they judged the boy to resemble his adoptive parent on more than 13 of the 18 features (significantly more than would be expected by chance).[3] Conversely, subjects were considered to have shown a *Biological Parent bias* if they had judged the boy to resemble his biological parent on more than 13 of the features (significantly more than chance). Finally, any pattern not falling into the other categories was considered to be a *Mixed* pattern.

Subjects of different ages gave markedly different patterns of judgments. As can be seen in Table 2, between the ages of 4 and 7, increasing numbers of children begin to appreciate that offspring resemble their birth parents with respect to some traits and their adoptive parents with respect to others. The association between age and the number of subjects in the Differentiated pattern was significant according to a chi-square analysis, crossing the four levels of age with the two levels of pattern (Differentiated vs. Not Differentiated), $\chi^2(3, N = 64) = 28.44$, $p < .001$.

The finding of greatest theoretical importance here is that most of the children under the age of 7 did not show a Differentiated pattern. As this is the only pattern providing clear evidence that subjects distinguished two mechanisms underlying resemblance to parent, these results undermine the claim that preschoolers *as a group* understand biological inheritance. Note, however, that it is entirely possible that *individual* preschoolers might have such an understanding. A second-order application of the binomial theorem, based on a probability of .02 that a subject would show a Differentiated pattern by chance, indicates that the 15 adults ($p < .001$), nine 7-year-olds

[3] It is, of course, statistically possible for subjects with Differentiated judgment patterns to meet these criteria (this was, in fact, true of only one child in our study). Note, however, that our hypothesis was that young children do not selectively associate the origin of physical traits with the biological father and beliefs with the adoptive father. Therefore, we first determined which subjects could be included in the Differentiated pattern group, the group most directly relevant to testing our hypothesis. The bias patterns therefore apply only to those subjects not included in the Differentiated group. This method of analysis credits children with the most advanced understanding possible.

TABLE 2

PATTERNS OF JUDGMENTS FROM STUDY 1, BY AGE

	Age			
Pattern	Adults	7	6	Preschoolers
Differentiated	15	9	4	1
Biological bias	0	3	3	1
Adoptive bias	0	1	0	6
Mixed	1	3	9	8

($p < .001$), and four 6-year-olds ($p < .001$) who showed this pattern are in each case significantly more than would be expected by chance out of a group of 16. However, the same is not true of the single preschooler (in the group of 16) who showed a differentiated pattern. It is therefore probable that *some* of the 6-year-old children understood biological inheritance, though most did not, whereas such a claim cannot be made regarding preschoolers.

Of the children who did not show a Differentiated pattern, a substantial number of preschoolers showed an Adoptive Parent bias. It is possible that these children may think learning or environmental factors mediate the acquisition of all properties. Children with a Biological Parent bias (shown almost exclusively by 6- and 7-year-olds) may think that birth mediates the acquisition of all properties. Or it may be that children in both groups responded solely on the basis of resemblance to parents, but had different criteria for determining what constitutes "parent." The modal pattern shown by both the 6-year-olds and the preschoolers was the Mixed pattern. This pattern may reflect random or inconsistent judgments or it may reflect judgments based on a different set of criteria than is reflected in the distinction between adoptive and biological parents.

The Mixed group likely also includes those subjects who have begun to distinguish two mechanisms underlying resemblance to parents, but who, for whatever reason, do not distinguish between the Physical features and Beliefs quite sharply enough to show a Differentiated pattern. Let us define the *Partially Differentiated* pattern group as including those subjects in the Mixed pattern group who judged the boy to resemble his father on at least half (three) of the Physical features and on fewer than half (one or none) of the Beliefs. A subject would have a chance probability of .33 of meeting these more liberal criteria, as determined by the binomial theorem. One adult, one 7-year-old, two 6-year-olds, and one preschooler showed this pattern. Note that even when we combine these subjects with those in the Differentiated group, the results still weigh against the claim that preschoolers overall understand biological inheritance. A second-order application of the binomial theorem indicates that the two preschoolers and the six 6-year-olds showing a Differentiated or Partially Differentiated pattern are not significantly more than would be expected by chance at each age, whereas the 10 7-year-olds ($p < .02$) and 16 adults ($p < .001$) are significantly more than would be expected.

Explanations.—The children were encouraged to explain their judgments (adults were not asked for explanations). The explanations were coded to reveal evidence of whether some children explicitly know causal mechanisms that selectively underlie resemblance to parents on physical traits and those that underlie resemblance on beliefs. Therefore, the explanations were coded as *Biological Parent, Nurture,* or *Other* (described below). Each response was assigned to the most sophisticated category possible. Two experimenters coded the justifications, independently of the judgments to which they applied, with 95% agreement; disagreements were resolved by fisticuffs.

The *Biological Parent* justifications were those responses that invoked the difference between the biological and adoptive parents in explaining the feature judgments. This category included a wide variety of possible responses all making reference to the fundamental difference between the fathers ("because he was born with the shepherd," "because the king was his real father," etc.). There were children who used "he's his father" to justify both biological and adoptive father judgments without distinguishing in any other way between the fathers. These responses were coded as *Other.*

Nurture justifications were those responses that referred to the father's role in raising the boy or to a specific mechanism such as teaching, learning, or self-discovery. The explanation "because he got used to it" was also considered a nurture explanation because it implied a change due to experience. Other examples of nurture explanations are "because he was with him more time, so he could have learned," "because he was with cats longer," and "because the king took him out [to the movies] a lot."

The *Other* category simply included those responses not characterized by the previous categories, even when loosely interpreted. The responses "I don't know" as well as simple failures to respond were included in this category. Many of these explanations suggest that some children judged the boy to resemble his father on particular features based on reasoning that ignored parentage in favor of external considerations such as the children's own beliefs about the desirability or truth of a particular property in the world (e.g., "because cats are nicer," "because it's better to share," and "because hearts are red"). Explanations of this type likely reflect the difficulty some children had in seeing the relevance of the distinction between biological and adoptive parents to the questions at hand, leading them to reason from the trait alone.

Children varied in the number of spontaneous justifications that they gave, and six children gave no explanations at all (three of them fell in the Adoptive Parent bias and three in the Mixed pattern group). Twelve of the 14 children in the Differentiated group ever gave a Biological Parent explanation for any trait, as did 20 of the 34 children in the Nondifferentiated groups. Interestingly, all seven of the children in the Biological Bias group gave at least one explanation of this type, whereas only one of the seven children in the Adoptive Bias group did so. Thirteen of the 14 children in the Differentiated group and 13 of the 34 children in the Nondifferentiated groups ever gave a Nurture explanation. That only one of the seven children in the Adoptive Bias group did so suggests that these children did not think that some psychological mechanism mediated resemblance on all traits, but, rather, that they were at a loss to explain their judgments. Finally, eight of the 14 children in the Differentiated group and 22 of the 34 children in the Nondifferentiated groups ever gave an Other explanation (and many of these children, three of the children in the Differentiated group and 16 of those in the Nondifferentiated groups, gave explanations that referred to the desirability or probability of the features).

Children who understand two distinct types of mechanisms underlying resemblance to parents should give Biological Parent explanations for their judgments that physical traits, but not beliefs, are inherited from birth parents and they should give Nurture explanations for their judgments that children acquire beliefs, but not physical traits, from the parents that raise them. Furthermore, when children judge the boy to resemble his birth parent on a Preference, Temperament, or Skill, they should give a Birth Parent explanation, and when they judge him to resemble his adoptive parent, they should use a Nurture explanation. (Note that our argument concerning the Preferences, Temperaments, and Skills does not hinge on which parent we a priori think the boy will resemble.) Following this reasoning, children were considered to have shown such a *Selective* pattern to their explanations if (1) they gave at least one Biological Parent explanation for the Physical traits or for a Preference, Temperament, or Skill they judged to be like that of the birth parent, but never did so for the Beliefs or for the Preferences, Temperaments, and Skills they judged to be like that of the adoptive parent; and (2) they gave at least one Nurture explanation for Beliefs or for a Preference, Temperament, or Skill they judged to be like that of the adoptive parent, but never did so for the Physical traits or for the Preferences, Temperaments, or Skills they judged to be like that of the birth parent. The *Not Selective* pattern included all of the other children.

Eleven of the 14 children in the Differentiated group showed the Selective pattern, but only two of the 34 children in the Nondifferentiated groups did so. A chi-square analysis, crossing the two levels of explanation pattern (Selective and Not Selective) with the two levels of inheritance judgment pattern (Differentiated and Nondifferentiated), was significant, $\chi^2(1, N = 48) = 26.53, p < .001$. This analysis supports the inference from the judgment patterns that the children in the Differentiated group are likely to be explicitly aware that distinct processes mediate the acquisition of physical features and beliefs. Note that the results do not necessarily indicate that the children in the Nondifferentiated groups believe that psychological mechanisms mediate resemblance on Physical traits. Only six of the 34 children in the Nondifferentiated groups ever gave Nurture explanations of their judgments of Physical resemblance and only nine children ever gave Birth Parent explanations of their judgments of resemblance on the Beliefs. Rather, most of the children in the Nondifferentiated groups produced Other explanations or no explanation at all.

Discussion

Children's judgment patterns and explanations tell a consistent story and appear to undermine the broad claim that preschool children have a biological understanding of inheritance. Only 56% of the 7-year-olds, 25% of the 6-year-olds, and 6% of the preschoolers selectively differentiated between the origins of physical traits and beliefs. Rather, most of the preschoolers and 6-year-olds displayed a Mixed pattern to their judgments. This pattern group may have included those who simply responded randomly as well as those who based their judgments on another set of criteria such as the desirability or probability of the individual features rather than upon the nature of the fathers. The children who judged that the boy would resemble the adoptive father in almost all respects may merely have based their judgments on resemblance to parent alone, considering the parent that raised the boy to be the relevant parent. Their explanations suggest that it is unlikely that they believed that teaching and learning can affect physical traits, for very few gave either Nurture or Biological Parent explanations.

We speculate that children with a Biological Parent bias may be a transitional group, both in age (only one preschooler showed this pattern) and in conceptual development. Their explanations suggest that they understand that birth plays an important role in resemblance to parent, but they do not yet appear to have worked out its role in mediating resemblance on only certain traits. These children judged that virtually all traits would resemble those of the birth father. They may realize the importance of birth in determining who the "real" father is, and then globally judge the boy to resemble his "real father" without differentiating among types of traits. It is unlikely that these children truly considered birth as part of the process that fixes all of the boy's traits, for such judgments are baldly inconsistent with the awareness children of this age have demonstrated previously that processes such as teaching and learning fix beliefs (e.g., Hogrefe, Wimmer, & Perner, 1986; Sullivan & Winner, 1991; Zaitchik, 1991).

These results undermine Springer and Keil's (1989) claim that young children understand biological inheritance, even though they are actually in accord with their results. Springer and Keil found that most 4–6-year-old children do not consider the origin of a feature (whether the parents had acquired the feature through birth or through life experience) to be a factor in their judgments of whether offspring would be born with that feature. In other words, their children, like most of ours, failed to appreciate that birth plays a central and selective role in the chain of causation that fixes physical traits. And, like us, they found that it is only at about age 7 that most children begin to show such an understanding.

Study 2: What Can Change and How

It is possible that children understand that some physical features are initially determined at birth, by the same process by which the animal comes into being, but also believe that these features can later change so as to match those of an adoptive parent. For example, one child in Study 1 judged that the prince started out with brown eyes (like his biological father), but that they turned green when he was adopted, because being adopted is like "being reborn." In other words, children may understand the biological inheritance of physical features, but allow for changes that adults do not. If so, then Study 1 may have underestimated children's understanding of biological inheritance. The principal goal of Study 2 was to assess whether children have intuitions about feature change that are radically different from those of adults. Subjects were asked directly whether a given set of features could change over the course of an individual's life. For those features judged changeable, subjects were then asked to explain their judgments.

There is evidence that young children do share many of our adult intuitions about feature change. For example, young children know that animals, unlike inanimate objects, grow in size over time, and that some mental features (e.g., having a quick temper) as well as some physical features (e.g., weight) can change, but they also know that some bodily features (e.g., skin color) do not change (Hirschfeld, in press; Inagaki & Hatano, 1993; Rosengren et al., 1991). Inagaki and Hatano (1993) have further shown that children understand that some bodily properties are not subject to a person's intentional control. They use this to claim that children distinguish two different explanatory frameworks for understanding distinct types of change in features, but this claim requires closer scrutiny. Inagaki and Hatano analyzed their subjects' explanations in order to determine whether children understand that the processes mediating the change of physical features are different from those mediating the change of mental features. They claimed that children were more apt to attribute changes in physical traits to *physical practice* (e.g., practice running to improve running speed) and to attribute change in mental traits to *mental practice*, volition, or effort (e.g., practice saying a phone number to improve memory). This claim is problematic, for though it is clear that *researchers* differentiate the two sorts of practice, it is not clear that *children* do.

A second goal of Study 2 was to relate children's understandings of feature change to their understandings of inheritance (the same subjects who took part in this study also took part in Study 3, an inheritance task very much like that of Study 1). This relation between these understandings is important, for biologically inherited features are those that are present at birth and do not change during the life cycle, or those that emerge through some maturational bodily processes and not through teaching. Of course, one prerequisite for constructing an understanding of inheritance is accepting the explanatory goal of accounting for the properties of individual people. Study 2 focuses children on this explanatory goal by asking them to reason about which features change and what causes these changes. Notice that if children have accepted this explanatory goal and understand the relevance of changeability to determining feature resemblance, then success on our inheritance task requires only inferences of the following sort: skin color does not change over development; babies resemble their parents in skin color; therefore, children's skin color will be the same as their birth parents'.

A final goal of Study 2 was to investigate whether children's judgments about feature change were influenced by the desirability of the features in question, as was suggested by many of the children's Study 1 explanations. The specific mental features that children had judged to be modifiable in Inagaki and Hatano's (1993) experiment were both undesirable temperaments (quick temperedness and forgetfulness), and the two bodily features judged modifiable (running speed and weight) also involved a change from less desirable (slow and skinny) to more desirable states. It is not clear that the judgments of Inagaki and Hatano's subjects would have been quite so adult-like had the proposed changes been from the more to the less desirable states.

Method

Sixteen new subjects in each of four age groups, adults, 7-year-olds (M = 7-7, range = 7-0 to 8-4), 6-year-olds, (M = 6-6, range = 6-0 to 6-11), and preschoolers (M = 5-2, range = 4-3 to 5-11), took part in Studies 2 and 3. They were drawn from the same population as those in Study 1.

The 10 feature pairs were like the 18 used in Study 1. In order to shorten the task, fewer trait pairs of each type were used: four *Physical traits*, two *Beliefs*, two *Preferences*, and two *Temperaments* (see Table 3). The Skills traits were eliminated entirely because they provided no additional information about children's reasoning; the children in Study 1 had judged and given explanations for the skills very much as they had for the preferences and temperaments. The individual beliefs and temperaments were chosen in order to test systematically whether desirability or probability played a significant role in children's judgments. Both of the temperaments were chosen because children were assumed to know which value was more socially or psychologically

TABLE 3

List of Study 2 Feature Pairs, by Trait Type

Physical traits:
is short/is tall
is black/is white
has liver on right/has liver on left
has baby teeth/has grown-up teeth
Beliefs:
believes that a red light means stop/believes that a red light means go
believes that a lion has 32 teeth/believes that a lion has 36 teeth
Preferences:
likes cats more than dogs/likes dogs more than cats
likes coconut/does not like coconut
Temperaments:
doesn't share things/shares things
laughs a lot/cries a lot

desirable. One of the beliefs (whether a red light means stop or go) was chosen because it was assumed that children would know what was true. The other belief (how many teeth a lion has) was chosen as a contrast because it was assumed that children would not know what was true. Two of the physical traits do change in the normal course of growth (the *Mutable Physical* traits) and two do not (the *Immutable Physical* traits). Both types were presented to avoid confounding the modifiability of a trait with its being physical. The features were presented in blocks by trait type. Half the subjects were presented with the Physical traits first, followed by Beliefs, Preferences, and Temperaments. The other half received the Beliefs first, followed by the Physical traits, Preferences, and Temperaments. The order of presentation of feature values within pairs was counterbalanced.

The subjects were asked whether the features of a child named Fred could change as he grew up (e.g., "Fred is a little boy about the same age you are. Fred's liver is on his left side. Could Fred change as he grows up so that his liver is on his right?"). The subjects gave a yes/no response. If they responded yes, they were asked to explain in their own words how this change might occur. After these free explanations, they were asked to judge the acceptability (yes/no) of both a body-related explanation ("Is there something about Fred's body that might make him change like that?") and a teaching/learning explanation ("Could somebody teach Fred to become taller?"). In order to facilitate comparisons between Studies 2 and 3, subjects were given corresponding versions. For example, those subjects who were told in Study 2 that Fred was white and were asked whether he could change to black as he grew up were told in Study 3 that the biological mother was white and the adoptive mother black.

Results

Yes/no responses.—All 16 of the adults, 7-year-olds, and 6-year-olds and 11 of the preschoolers judged that neither of the Immutable Physical traits could change. The probability of showing such a pattern by chance responding is .25. A second-order application of the binomial theorem indicates that even the 11 preschoolers are significantly more than would be expected by chance ($p < .001$). The results weigh against the strong claim that children have a radically different sense that certain physical traits can change. But this is not to say that their judgments of feature change were entirely adult-like.

Desirability/probability Response Bias.—It was assumed that subjects might base their judgments on the desirability of the features and not on any principled reasoning about feature acquisition and change. Therefore, for each of the comparisons in which one state is more desirable than the other (the red light belief and both temperaments), half of the subjects were asked about change from the more desirable to the less desirable feature, and half were asked about change in the reverse direction.

Table 4 shows that the adults judged all of these features to be changeable, regardless of desirability. The children showed quite a different pattern. That is, the children were disproportionately more likely to say that Fred could go from believing that a

TABLE 4

Desirability Judgments from Study 2

Direction of Change	Children's Judgment: Yes	Children's Judgment: No	Adult's Judgments: Yes	Adult's Judgments: No
Belief: traffic light:				
Undesirable to desirable	23	1	8	0
Desirable to undesirable	3	21	8	0
Temperament: sharing:				
Undesirable to desirable	22	2	8	0
Desirable to undesirable	14	10	8	0
Temperament: mood:				
Undesirable to desirable	19	5	8	0
Desirable to undesirable	6	18	8	0

red light means go to believing that it means stop than from believing that it means stop to believing that it means go, $\chi^2(1, N = 48) = 33.57, p < .001$; they were disproportionately more likely to say that he could go from not sharing to sharing than the reverse, $\chi^2(1, N = 48) = 7.11, p < .008$; and that he could go from being angry a lot to laughing a lot than the reverse, $\chi^2(1, N = 48) = 14.11, p < .001$.

These results bear directly on Inagaki and Hatano's (1993) finding that children judged mental and physical features to be modifiable much as adults might. The particular modifiable features they used were undesirable temperaments or bodily features that the children then judged could change into more desirable features. In light of our finding that desirability is a large factor in children's reasoning about feature change, the children in Inagaki and Hatano's study may not have been as adult-like in their reasoning about feature change as they would appear.

The Study 2 results are consistent with the suggestion from Study 1 that children are likely to weigh a feature's desirability too strongly in reasoning about feature acquisition. This tendency cannot result from children's ignorance of the mechanisms of belief fixation, for we know from the theory of mind literature that 4-year-olds are able to attribute false beliefs on the basis of an actor's exposure to information (e.g., Hogrefe et al., 1986; Sullivan & Winner, 1991; Zaitchik, 1991). It may be that the children understood the task not so much as testing the possibility of change but the probability of change, and it is indeed highly improbable that someone in our culture could believe that, for example, a red light means go. Perhaps the young children lent such pragmatic factors greater weight than did the adults who, with their metacognitive understanding that these questions are about the influence of nature and nurture, focused only on the mechanism relevant to such a conflict and ignored the feature's desirability. Many of the children, by contrast, may have failed to see the relevance of mechanisms of change and so resorted to considerations of probability or desirability.

Free explanations.—Children's free explanations for those features they considered changeable were coded and analyzed. Of particular interest is whether they understood that bodily processes mediate change in physical features and teaching and learning mediate change in beliefs. Two researchers coded the explanations into the following three categories with 92% agreement.

Teaching explanations included all explicit appeals to teaching and learning as well as those justifications that referred to some particular piece of evidence that Fred would acquire (e.g., Fred might change his belief about the number of teeth a lion has because "he will go to a zoo, not a zoo, to a, yeah, a gypsy carnival and see them doing tricks and the lion might open his mouth and he could count very quickly").

The *Body-related* explanations included those that referred to some bodily process. Almost all were of the specific sort "you get taller because you eat" or "you get grown-up teeth because your baby teeth fall out." Appealing to Fred's *growing up* as an explanation for how features change as he *grows up* is tantamount to restating the given information. Such explanations describe no processes and so were considered to be Other explanations.

The Other explanations did not appeal to mechanisms at all. They included those explanations that merely restated the child's judgment that the feature will change, appeals to a canonical direction of change (e.g., "because everyone gets taller"), confirming instances (e.g., "because I changed like that"), and mere restatements of the information provided (e.g., "he'll get taller because he'll grow"). These explanations also included appeals to the feature's desirability (e.g., "because it's better to be tall") or truth (e.g., "because red lights really do mean stop").

Nine of the preschoolers, 10 of the 6-year-olds, and 12 of the 7-year-olds ever gave a Teaching explanation for any trait. Eight of the preschoolers, nine of the 6-year-olds, and 11 of the 7-year-olds ever gave a Body-related explanation for any trait. Almost all of the children (81%) gave at least one Other explanation. Of these, five of the preschoolers, nine of the 6-year-olds, and six of the 7-year-olds explained the change in terms of the desirability of the features. Finally, two of the preschoolers, two of the 6-year-olds, and one of the 7-year-olds never gave any explanations.

Recall that we were particularly interested in whether children would appeal to teaching explanations for changes in beliefs and bodily explanations for physical changes. We considered children to have shown a *Selective* explanation pattern if they gave a Body-related explanation for the change of at least one Physical trait, but never for a Belief, and if they gave at least one Teaching explanation for at least one Belief, but never for a Physical trait. Any other pattern was considered a *Not Selective* explanation pattern. Five of the preschoolers, four of the 6-year-olds, and eight of the 7-year-olds showed the Selective explanation pattern. A chi-square analysis crossing the two levels of explanation pattern type with the three levels of children's age was not significant.

Consistent with Inagaki and Hatano's (1993) findings, teaching was never used to explain physical changes, but fewer than half of the children showed a Selective explanation pattern. Recall that after giving their free explanations, children were also asked to judge whether two presented explanation types could explain the changeability of the trait ("Is there something about Fred's body that might make him change like that?" and "Could somebody teach Fred to become [feature]?"). Unfortunately, the question is flawed, so it is not clear that children understood the body explanation that was being proposed.[4] Therefore, we have dropped the Presented Explanations from our analyses. It is striking that only about half of the preschoolers referred to bodily mechanisms at all in their free explanations given that for every trait they judged mutable they were asked whether there "was something about Fred's body that might make him change."

Discussion

The results of Study 2 demonstrate that children's failure in Study 1 cannot be attributed simply to a belief that immutable physical traits can change. Even preschoolers demonstrated, in their judgments of possible change of physical traits and in many of their explanations, that they generally share our adult intuitions. Their explanations further reveal that they understand that teaching and learning will not affect even those physical traits that can change. These results are consistent with the finding that children distinguish between mental and physical objects (Wellman & Gelman, 1992) and realize that there are some bodily phenomena over which we do not have intentional control (Inagaki & Hatano, 1993). Study 3 allows us to examine how children's awareness of the constrained processes involved in feature change relates to their awareness of the processes involved in inheritance.

Study 3: Similarity to Adoptive and Biological Parents, Redux

The results of Study 1 undermine the claims that preschool children understand biological inheritance. This may be because, as we have claimed, previous studies failed to examine the necessary contrast between biological and adoptive parentage. The principal goal of Study 3 was to relate children's judgments of resemblance to parents to their Study 2 judgments of feature change; this conjunction of tasks addresses the possible objection that children performed as they did in Study 1 because they have a different understanding of what physical traits can change over a lifetime. Study 3 also addressed the possibility that certain methodological aspects of Study 1 masked children's understanding. For example, these children may have been less aware of the biological relations between children and their fathers than of that between children and their mothers. Furthermore, the sheer number and variety of features probed may have simply overwhelmed the youngest children.

Method

Subjects took part in Study 3 immediately after Study 2. The stimuli and procedure were nearly identical to those of Study 1, but with changes designed to lessen the task demands. First, the task was shortened to include nine instead of 18 feature pairs: three physical traits, two beliefs, two preferences, and two temperaments (see Table 3). The features were identical to those used in

[4] In accepting the body explanation for the change of Beliefs, the children might have reasoned that because thinking occurs in the brain, and because the brain is part of the body, there is something about Fred's body that could cause him to change beliefs. Such children would then have seemed not to distinguish bodily and psychological mechanisms. Moreover, it is not even clear what we are to infer from children's acceptances of the body explanation for the change of physical traits. It verges on the tautological to say that something about the body explains changes in the body. The children may simply be answering that the physical traits are of the body. Finally, because the explanations are for those features that were judged changeable, we get a skewed sample, for we do not represent the thinking of the children on features they erroneously judged not changeable.

Study 2, except that the teeth feature pair (forcing children to choose between a parent with grown-up teeth and one with baby teeth) was dropped. Second, because children understand some role of the mother in birth and creation long before they understand the involvement of the father (Bernstein & Cowan, 1975), the story was changed to involve a queen and a shepherdess rather than a king and shepherd (see Appendix B). Third, the procedure no longer involved the pictures of the parents and the baby because of the possibility that those pictures may somehow have influenced the subjects' judgments in Study 1. The pictures of the castle and the hut were still used. The traits were grouped by type to facilitate the children's abilities to access and apply whatever knowledge they think relevant. Finally, the study was balanced across subjects to control for the order in which the blocks of traits were presented (i.e., Physical, Belief, Preference, then Temperament as opposed to Belief, Physical, Preference, Temperament), for whether the queen or the shepherdess was associated with particular features (e.g., half of the subjects were told that the queen is short and half were told that the shepherdess is short), and for whether the queen or the shepherdess is the biological mother. As in Study 1, a preliminary analysis revealed no significant order effects.

Results

Pattern of responding over trait types.— The subjects' overall judgment patterns were sorted according to the patterns of responding introduced in Study 1. As in Study 1, we note that subjects at all ages generally judged the acquisition of the Preference-Temperament traits and the Beliefs similarly. Therefore, we focus on the contrast of the physical traits and beliefs. The *Differentiated* pattern group was defined to include those children who had judged the girl to resemble her biological mother on all three of the physical traits but on none of the beliefs. The binomial theorem indicates that a subject has a chance probability of .03125 of showing this pattern. Of those subjects who did not meet these criteria for inclusion into the Differentiated pattern group, three further categories were defined. Subjects were considered to have shown an *Adoptive Parent bias* pattern if they judged the girl to resemble her adoptive parent on more than seven of the nine features (significantly more than would be expected by chance). Conversely, subjects were considered to have shown a *Biological Parent bias* if they had judged the girl to resemble her biological parent on more than seven of the features (significantly more than chance). Finally, those patterns not described by the above categories were considered *Mixed* patterns. The results are presented in Table 5.

The number of subjects showing the Differentiated pattern as opposed to any other pattern varied significantly by age, $\chi^2(3, N = 64) = 23.90, p < .001$. A second-order application of the Binomial theorem, based on a chance probability of .03 of showing this pattern, indicates that the 16 adults ($p < .001$), 10 7-year-olds ($p < .001$), six 6-year-olds ($p < .001$), and three preschoolers ($p < .05$) showing this pattern were all more at each age than one would expect by chance. Again, it is likely that *some* preschoolers command the understanding of biological inheritance tapped by this task. We emphasize, rather, that there is insufficient ground for the claim that preschoolers *as a group* understand biological inheritance. Most of the children under 7 years of age showed a Nondifferentiated pattern.

As in Study 1, the Adoptive Parent bias was shown more by the preschoolers than any other age group, the Biological Parent bias was shown most by the 6-year-olds, and relatively fewer of the 7-year-olds than of the younger children fell into the Mixed category. Again, the Mixed pattern group was

TABLE 5

Patterns of Judgments from Study 3, by Age

	Age			
Pattern	Adults	7	6	Preschoolers
Differentiated	16	10	6	3
Biological bias	0	0	2	1
Adoptive bias	0	1	0	3
Mixed	0	5	8	9

further analyzed to identify the subgroup of subjects who showed a *Partially Differentiated* pattern. This pattern was liberally defined to include those subjects who judged the girl to resemble her biological mother on more than half (two or three) of the Physical features and on at most half (one or none) of the Beliefs. Even when we combine the four 7-year-olds, two 6-year-olds, and three preschoolers who showed this pattern with those in the Differentiated group, we do not find that most of the 6-year-olds and preschoolers meet these more liberal criteria. A second-order application of the binomial theorem (based on a chance probability of .38 of showing such a pattern) indicates that the six preschoolers and eight 6-year-olds showing a Differentiated or Partially Differentiated pattern are not significantly more than would be expected by chance at each age, whereas the 14 7-year-olds ($p < .001$) and 16 adults ($p < .001$) are significantly more than would be expected. These results support the Study 1 findings that most children under the age of 7 did not demonstrate an understanding of biological inheritance.

More children showed the Differentiated pattern and the Partially Differentiated pattern in Study 3 than in Study 1, but comparisons between children's performances in Studies 1 and 3 must be made cautiously. The binomial theorem indicates that the chance probability of showing a Differentiated pattern is slightly greater in Study 3 (.03) than it is in Study 1 (.02), as is the probability of showing a Partially Differentiated pattern (.38 as compared to .33). Nonetheless, the distribution of patterns by ages in the two studies is quite similar.

Explanations.—The subjects were asked to justify all of their judgments and their responses were coded according to the Study 1 classifications (*Biological Parent, Nurture,* and *Other*). Two researchers coded the explanations with 99% agreement. Again, we looked for the association of Biological Parent explanations with acquisition of Physical traits and Nurture explanations with the acquisition of Beliefs. As in Study 1, we considered children to have shown a *Selective* explanation pattern if they gave at least one Biological Parent explanation for the physical traits and never for the beliefs, and gave at least one Nurture explanation for the beliefs, but never for the physical traits. The *Not Selective* pattern included all of the other children.

Fourteen of the 19 children in the Differentiated group showed the Selective pattern, but only three of the 29 children in the Nondifferentiated groups did so. A chi-square analysis, again crossing the two levels of explanation pattern (Selective and Not Selective) with two levels of inheritance judgment pattern (Differentiated and Nondifferentiated) showed a significant association between explanation pattern and inheritance judgment pattern, $\chi^2(1, N = 48) = 20.13$, $p < .001$. These analyses of the children's explanations were consistent with the inheritance judgment results: The children in the Differentiated inheritance pattern group were far more likely than the other children to make explanations differentiating between those processes mediating the acquisition of physical features and those mediating the acquisition of beliefs.

Comparison to Study 2 changeability judgments.—A comparison of Studies 2 and 3 allows us to reject the possibility that those children who judged offspring to resemble their adoptive parents on physical features had a radically different sense from adults of what features can change. Children as a group made adult-like changeability judgments (at least on those feature pairs for which one value was not clearly preferable), but still failed to make adult-like inheritance judgments. Let us look at the judgments in the two studies on a within-subject basis. The Immutable Physical traits of race and liver position bear most directly on the relation of children's understanding of biological inheritance to their understanding of feature change. Twenty-one times children judged the girl to resemble her adoptive mother on these traits, but only four times did they also judge those traits changeable after birth.

Many children appeared unaware that changeability had any relevance whatsoever to judgments about inheritance. For example, one child judged the girl to be white like her adoptive mother, though he had minutes earlier judged that a person could not change from being black to being white. After the experiment, when asked again for his judgments on race, he repeated his earlier responses. When asked what color the little girl would be when she was born, he said "white [the color of the adoptive parent], because race cannot change." Clearly, children's notions of the changeability of a physical feature does not adequately account for why their resemblance judgments diverge from those of adults.

Comparison of Studies 2 and 3 allows us to pursue the question of whether those children who understand changeability in Study 2 to be mediated by selective mechanisms will be more likely to understand resemblance to parents in Study 3 to be mediated by selective mechanisms (though not necessarily the same mechanism). Nine of the 17 (53%) children who showed a selective pattern of explanation of changeability in Study 2 also showed a selective pattern of explanation of resemblance to parent in Study 3, whereas only eight of the 31 (26%) children who did not show a selective pattern of explanation in Study 2 did show a selective pattern of explanation in Study 3. A chi-square analysis, crossing two levels of Study 2 explanation pattern (Selective vs. Not Selective) with two levels of Study 3 explanation pattern (Selective vs. Not Selective) shows that this association falls just short of significance, $\chi^2(1, N = 48) = 3.54$, $p = .06$.

Discussion

The results of Study 3 were very much in keeping with those of Study 1: It is only at age 7 that most children make differentiated judgments and give explanations that reveal an understanding of birth as part of a causal chain mediating the fixing of immutable physical features. Study 2 shows that children do understand that such features as race and liver position cannot change; what most do not understand is the role of the biological parent in determining them in the first place. In Study 2, explanations that referred to explicit mechanisms of change did not account for more than about a third of all explanations given by children at any age. But when the children are grouped by Study 3 inheritance pattern, we see a coherence to their judgments. Children in Study 3 who were more likely to make explanations that implied that they were aware of distinct causal chains mediating resemblance to parents (those in the Differentiated groups) were more likely to make Study 2 explanations that implied an awareness of distinct causal chains mediating feature change. These tasks may well tap the same system of understanding. There may be a conceptual coherence to children's understandings of these seemingly separate phenomena; understanding which features can and cannot change is related to an understanding of what mechanisms determine what those features are likely to change into. It is this kind of coherence of understanding that defines a domain of biology.

Study 4: Similarity to Adoptive and Biological Parents, Redux Redone

Study 4 addressed the possibility that aspects of the methodologies of Studies 1 and 3 prevented young children from demonstrating an understanding of inheritance they in fact possess. Perhaps our placing the story in the context of a fairy tale led children to accept magical transformations. And perhaps our including traits that differed in desirability and our including preferences and temperaments distracted children from the contrast of interest. Study 4 differed from Studies 1 and 3 in each of these respects and also in its simplified wording of the general instructions. At issue is whether preschoolers would now succeed at the task.

Method

Sixteen preschoolers (M = 5-0, range = 4-2 to 5-10), drawn from the same population as those in the previous three studies, took part in the study. Subjects were told an adoption story in which a woman in a hospital dies immediately after giving birth to a baby girl and another woman then adopts the baby girl and takes her back to live with her (see Appendix C). In addition to avoiding the fairy tale nature of the previous stories, the hospital story also eliminates the possibility that the biological mother could have visited the adopted child and so influenced her. Furthermore, the subjects were no longer shown pictures of the homes of the mothers, but rather were shown schematic pictures of the mothers in order to lessen the focus on environmental factors. The wording of the instructions was simplified and more repetition was included in order to make it less likely that subjects simply did not understand what judgments they were being asked to make. The list of features no longer included preferences or temperaments, but only five physical features and five beliefs, the contrast of most interest (see Table 6). Moreover, subjects were asked to judge only immutable physical features so as to focus their attention on how those features were initially determined. Finally, the features were chosen so that one feature of each pair was not inherently more desirable than the other.

As in Study 3, the Beliefs and Physical traits were presented in blocks to highlight

TABLE 6

LIST OF STUDY 4 FEATURE PAIRS, BY TRAIT TYPE

Physical traits:	
Brown eyes	Green eyes
Liver on right [something inside you]	Liver on left
Turned up nose [like this]	Turned down nose [like this]
Blonde hair	Red hair
Flat appendix [something inside you]	Round appendix
Beliefs:	
Lion has 40 teeth	Lion has 30 teeth
Aardvarks eat only meat	Aardvarks eat only plants
To bake a cake put oven at 300°	To bake a cake put oven at 400°
Mr. Rogers lives in a city called Chicago	Mr. Rogers lives in a city called Seattle
Rock called feldspar is gray	Rock called feldspar is black

the contrast of trait types. The study was also balanced across subjects to control for the order in which the blocks of traits were presented (i.e., Physical then Beliefs as opposed to Beliefs then Physical), for which parent was described first (the biological or the adoptive parent), and for the order in which the five feature pairs within each trait type were presented.

Results and Discussion

Pattern of responding over trait types.—The children's judgments were analyzed according to the Study 1 and 3 inheritance pattern groups. The *Differentiated* pattern group was defined to include those children who had judged the girl to resemble her biological mother on at least four of the five Physical traits and on at most one of the Beliefs. The binomial theorem indicates that a subject has a chance probability of .03516 of showing this pattern. Of those subjects who did not meet these criteria for inclusion into the Differentiated pattern group, three further categories were defined. Subjects were considered to have shown an *Adoptive Parent bias* pattern if they judged the girl to resemble her adoptive parent on more than seven of the 10 features (significantly more than would be expected by chance). Conversely, subjects were considered to have shown a *Biological Parent bias* if they had judged the girl to resemble her biological parent on more than seven of the features (significantly more than chance). Finally, those patterns not described by the above categories was considered *Mixed* patterns.

None of the preschoolers showed the Differentiated pattern. Eight preschoolers showed the Adoptive Parent bias, four showed the Biological Parent bias, and four showed a Mixed pattern. Again, the Mixed pattern group was analyzed to identify the subgroup of subjects showing a *Partially Differentiated* pattern. This pattern was defined to include those subjects who judged the girl to resemble her biological mother on more than half (at least three) of the Physical features and on at fewer than half (at most two) of the Beliefs. The Binomial theorem indicates that subjects have a chance probability of .25 of showing this pattern. A second-order application of the binomial theorem indicates that the two preschoolers who showed this pattern are not significantly more than would expected by chance. Therefore, despite methodological alterations, these results support the Study 1 and 3 findings that most preschoolers did not demonstrate an understanding of biological inheritance.

General Discussion

Callanan and Oakes (1992, pp. 221–222) provide a striking example of a 4-year-old's unadult-like understanding of resemblance to family:

> Child: Why does Daddy, James [big brother], and me have blue eyes and you have green eyes?
> Parent: [Told her she got her eyes from Daddy. Then said goodnight and left the room.]
> Child: [Child calls mother back 5 minutes later.] I like Pee Wee Herman and I have blue

eyes. Daddy likes Pee Wee Herman and he has blue eyes. James likes Pee Wee Herman and he has blue eyes. If you liked Pee Wee Herman you could get blue eyes too.

Parent: [I told her it would take more than my liking Pee Wee Herman to make my eyes blue. I realized that she didn't understand me, so I explained that God gave me this color and that they couldn't be changed.]

Child: Could you try to like Pee Wee Herman so we could see if your eyes turn blue?

Consistent with this anecdote, the results of our studies refute the broad claim that preschool children understand biological inheritance. This child expected resemblance to family for eye color, but had no ideas about the biological mechanisms underlying it. As argued above, a child's understanding of inheritance is uniquely biological only if it is embedded within a conceptual framework that explains resemblance to parent on physical traits in a manner distinct from that explaining resemblance on beliefs. With our adult notions of biology and psychology, we understand that children adopted at birth will tend to resemble their biological parents on bodily traits because of one chain of causal processes (of which birth is a crucial element) and their adoptive parents on beliefs because of another chain of processes (typically involving teaching or learning). For the most part, the preschoolers and 6-year-olds in Studies 1, 3, and 4 neither differentiated among features by trait type in deciding which parent the offspring would resemble, nor differentiated among trait types in their explanations. They failed our task.

What might the children's failure mean? Many of them demonstrated a bias to judge the little boy or girl to resemble one parent on virtually all traits. These children may not have been thinking about causal processes at all, but may simply have based their judgments upon their knowledge that offspring resemble their parents, decided which parent was the "real" parent, and then judged the offspring to resemble that parent on all traits. It is possible that some of the children who showed a biological parent bias may have begun to understand that birth plays a role in determining who is the "real" parent, but they have evidently failed to understand how birth might be part of a series of causal processes that selectively fixes bodily traits and not beliefs. The children who showed a Mixed pattern also lacked this understanding. Many of these children may simply have judged the features randomly. But in Studies 1 and 3, others may, in a nonrandom fashion, have considered the desirability or probability of a feature to be of determining importance, regardless of parentage. In either case, these children did not differentiate among features in a systematic enough fashion to indicate that they understood resemblance to parents to be mediated by distinct chains of causal processes.

The failure of the young children was not due to their lack of some domain-general ability to reason causally, for there is convincing evidence that they understand causation within the cognitive domains of psychology and mechanical physics (e.g., Carey & Spelke, 1994; Leslie, 1994; Wellman & Gelman, 1992). And Study 2 indicated that this failure was not due to their having a radically different sense from adults of what physical features can change. Instead, the children's failure is likely due to their ignorance of uniquely biological mechanisms relevant to the origin and determination of bodily features.

Previous studies directly asking preschool children about origins reveal that they know that people are involved in the origin of artifacts and their properties, but not in the origin of animals and plants and their properties (Gelman & Kremer, 1991; Keil, 1989; Springer & Keil, 1991). But knowing that people are not involved in some process is not the same as knowing the nature of the process. When directly asked how it is that rabbits come to hop or to have long ears, 4–7-year-olds have very little to say.

Springer and Keil (1991) attempted to circumvent young children's lack of knowledge of specific processes by asking them to choose from a set of explanations for how, for example, a flower gets its color. They depicted a flower growing inside another flower and asked how the baby flower came to be blue. Children accepted explanations in terms of sun and rain falling on the flower or those in which the mother gave the flower something that made it turn blue. They further accepted a mediating process in which the sun and rain melted some of the blue from the mother flower onto the baby. This study is very important, for it addresses how children constrain the explanations they find plausible for phenomena they as yet cannot explain, but it does not establish that they have constructed any specifically biological explanations for inheritance before age 7.

The study does confirm Gelman and Kremer's (1991) finding that children do not think that human agency plays a role in flower color. But beyond that, the children's choices of explanations are simply constrained by what they know about flowers and color. For example, the children accepted the explanation that "the flower turns blue because the sun and rain fell on the mother when the little flower was growing inside it." This, by itself, provides no mechanism at all; it is something children know about flowers—that sun and rain are necessary for growth. Furthermore, the explanations simply reflect general knowledge about color transfer: children only accept explanations wherein something becomes blue because it is covered with something blue. Finally, the study does not establish that children understand the role of reproduction in inheritance, for though they were told that the flowers were babies growing inside mothers, children of this age think it is a category mistake to talk about mother plants at all (Keil, 1979).

By the age of 7, most children succeeded at our tasks; they associated the physical traits with the biological parent and the beliefs with the adoptive parent and also made a sharp distinction between trait types in giving the nurture explanations and the biological parent explanations. What does their success indicate about their understanding? Certainly, the nurture explanations explicitly describe genuine causal mediating mechanisms (learning, being taught, getting used to it), but the birth parent explanations are ambiguous. It is not completely clear how deep an understanding of biological inheritance these children had.

We adults understand birth not so much as the single direct causal mechanism of inheritance, but as part of a causal chain. Ultimately, it is the biological parents who cause offspring to have certain of their biological properties (as we understand it, from the transmission of their genetic code). One might conceive of a number of alternative causal paths by which biological parents could influence their children, but only those causal chains that normally involve birth can be considered as part of biological inheritance. It may be that the children's birth parent explanations merely reflected their belief that the birth parent is the "real" parent, with no sense at all of causal processes involved. Yet, the fact that these children generally gave such explanations selectively for physical traits and not beliefs is indirect evidence that many of them were aware of birth as part of a causal process. The birth parent explanations, then, may have been a way of implicating birth as part of the chain of processes by which a brown-eyed father comes to have a brown-eyed son. Even if these children do not know what those processes are (and it is exceedingly unlikely that they do), they may know that such processes exist. Birth, in this sense, may function as something of a conceptual placeholder and as a constraint on later theories.

It may be that those children who succeeded on the inheritance task were in the process of constructing an autonomous cognitive domain of biology. Recall that the children in Study 2 who selectively referred to some body-related process in explaining the change of physical traits, but not the change of beliefs were also more likely to refer to birth in explaining resemblance on physical traits, but not resemblance on beliefs. These children may know that these ostensibly distinct phenomena within the domain are indeed explanatorily related by bodily processes, if processes more inferred than understood. One hallmark of domain-specific thinking is just this kind of theoretical coherence.

Of course, most of the preschoolers did not demonstrate an understanding of the greater relation of biological inheritance to other phenomena within the domain. How they eventually come to such an understanding is a question of critical importance, and the focus of ongoing research. Hirschfeld (in press) has argued that children first understand that certain essential properties (race in particular) are fixed at birth and that later children come to understand how other properties are fixed. Partially in response to a previous version of this paper, Hirschfeld conducted a study in which about three-quarters of the 4- and 5-year-old subjects in a "switched-at-birth" study judged an adopted girl to have the skin color of her birth parents rather than that of her adoptive parents. Hirschfeld may be correct in claiming that preschoolers have an essentialist understanding of race, but our Study 3 results directly contradict his findings. They indicate that preschoolers were *not* significantly more likely than chance to judge that the girl would resemble her birth parent on skin color. One possible explanation of this discrepancy is that we placed a greater emphasis than did Hirschfeld on the adoptive family as a *family*. Unlike Hirschfeld, we explicitly told our subjects that the little girl called her adoptive parent "Mother" and the parent called the little girl "Daughter." After all, we grant that preschoolers know that offspring are more likely to resemble family members than nonfamily members (e.g., Springer, 1992). Studies in our lab are currently exploring whether children have an essentialist understanding of species-kind much as Hirschfeld claims of race.

The present studies challenge the claim that preschoolers' understanding of inheritance is biological. And these data also challenge the claim that preschoolers have constructed an autonomous cognitive domain of biology insofar as that claim rests on their understanding biological inheritance. It may be that a different way of characterizing biological reasoning will better capture children's causal explanatory frameworks (e.g., Inagaki & Hatano, 1993; Keil, 1994), but the burden is upon those researchers who make such claims to demonstrate that preschoolers reason about a range of phenomena in a theoretically coherent manner. Suffice it to say that, in this nascent domain of research, such a claim is premature.

Appendix A

The King/Shepherd Stories

Version 1

Once upon a time, there was a king. Here is a picture of him. [Show king.] He lived in this big palace. [Show palace.] The king could not have children, but he wanted a child very much. So he went out into his kingdom where he met a shepherd who had many children. Here is a picture of the shepherd. [Show shepherd.] This is where the shepherd lived. [Show hut.] The shepherd loved all of his children and they loved him. The king told the shepherd that he wanted to adopt the shepherd's baby boy and raise him as his own son and that the baby would then grow up to be the prince. This is the shepherd's baby boy. [Show baby, place by hut, by shepherd.] The shepherd agreed that this was a good idea so the king adopted the baby boy and took him to the palace. [Place king and baby by palace.] The king loved the baby and the baby loved the king. The baby grew up in the palace with the king and became a prince.

Version 2

Once upon a time, there was a king. Here is a picture of him. [Show king.] He lived in this big palace. [Show palace.] The king had a baby son who he loved very much and who loved him too. [Show baby.] Here is a picture of a shepherd who loved children but didn't have any of his own. This is where the shepherd lived. [Show hut.] Unfortunately, there was a wicked witch who wanted to eat the king's baby. The king wanted to hide his baby son from the witch so he let the shepherd adopt the baby and take him back to live with him at the hut. [Place shepherd and baby by hut.] The shepherd loved the baby very much and the baby loved the shepherd. The baby grew up with the shepherd and the witch never found him.

Appendix B

The Queen/Shepherdess Stories

Version 1

Once upon a time, there was a queen. She lived in this big palace. [Show palace.] The queen could not have children, but she wanted a child very much. So she went out into her kingdom where she met a shepherdess who had many children. This is where the shepherdess lived. [Show hut.] The shepherdess loved all of her children and they loved her. The queen told the shepherdess that she wanted to adopt the shepherdess's little girl and raise her as her own child and that the little girl would then grow up to be the princess. The shepherdess agreed that this was a good idea so the queen adopted the little girl and took her to the palace. The queen loved the little girl and the little girl loved the queen. The queen called her "Daughter" and she called the queen "Mother." The little girl grew up in the palace with the queen and became a princess. She lived her whole life with the queen in the palace. Now the little girl is a young woman and we have some questions about what you think she's like now.

Version 2

Once upon a time, there was a queen. She lived in this big palace. [Show palace.] The queen had a little daughter who she loved very much and who loved her too. In the queen's kingdom there was also a shepherdess who loved children but didn't have any of her own. This is where the shepherdess lived. [Show hut.] Unfortunately, there was a wicked witch who wanted to eat the queen's little girl. The queen wanted to hide her little girl from the witch so she let the shepherdess adopt her daughter and take her back to live with her in the hut. The shepherdess loved the girl very much and she loved the shepherdess. The little girl lived with the shepherdess all of her life and the shepherdess called her "Daughter" and she called the shepherdess "Mother." The shepherdess raised the girl and when she grew up she became a shepherdess too. And the witch never found her. Now the little girl is a young woman and we have some questions about what you think she's like now.

Appendix C

The Study 4 Story

There was a woman named Mrs. Smith; here's a drawing of her [point to picture]. Mrs. Smith went into a hospital and gave birth to a baby girl. Here's a drawing of the baby just after she was born [point to picture]. Unfortunately, Mrs. Smith died right after having the baby and she never even got to see the baby. Fortunately, there was a really nice woman named Mrs. Jones who was visiting the hospital. See, here's a drawing of Mrs. Jones [point to Mrs. Jones]. Mrs. Jones saw what happened. She saw that a baby girl was born to Mrs. Smith, but that Mrs. Smith died right away [pointing to pictures]. Mrs. Jones always wanted to have a little girl, and she saw that the little baby girl was all alone, so she adopted the little baby girl and brought her home to live with her. Mrs. Jones loved the little girl very much and called her "Daughter" and the little girl loved Mrs. Jones very much and called her "Mommy." The little girl spent her whole life with Mrs. Jones.

Do you remember who the little baby girl was born to? And who did the little baby girl live with?

Now I'm going to ask you some questions about what you think the little girl is going to be like when she grows up into a young woman. Mrs. Smith has [feature X] and Mrs. Jones has [feature Y]. The little girl is grown up now. Does she have [X] like Mrs. Smith or does she have [Y] like Mrs. Jones? [pointing all the time].

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